State of Washington
DEPARTMENT OF FISH AND WILDLIFE
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January 13, 2021

TO: Erik Neatherlin, GSRO
Jennifer Johnson, GSRO

FROM: Laurie Peterson, WDFW

SUBJECT: FINAL WDFW Adult Abundance Status and Trends Analysis for 2020 SOS

Thank you for the opportunity to assist with this year's State of the Salmon Report. Attached please find our final two-part report (Part I titled "*Status and Trends Analysis of Salmon Abundance Data, Parts I and II*" and PART II titled "*Adult Abundance Analysis Review, Interpretation by Salmon Recovery Partners*"). We are very pleased with the outcome of our effort to assist GSRO, and believe we have all set the stage for further collaboration, greater consistency, and more transparency in reporting salmon recovery abundance. GSRO's State of the Salmon Report is an ideal pathway to disseminate sound science to a broader public. We in the Fish Science Division are very appreciative of this opportunity and look forward to such collaborations in the future. Please feel free to call or email with questions (360/972-5844, laurie.peterson@dfw.wa.gov).

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FINAL

PART I

Status and Trends Analysis of Adult Abundance Data

Prepared in Support of
Governor's Salmon Recovery Office
2020 State of Salmon in Watersheds Report

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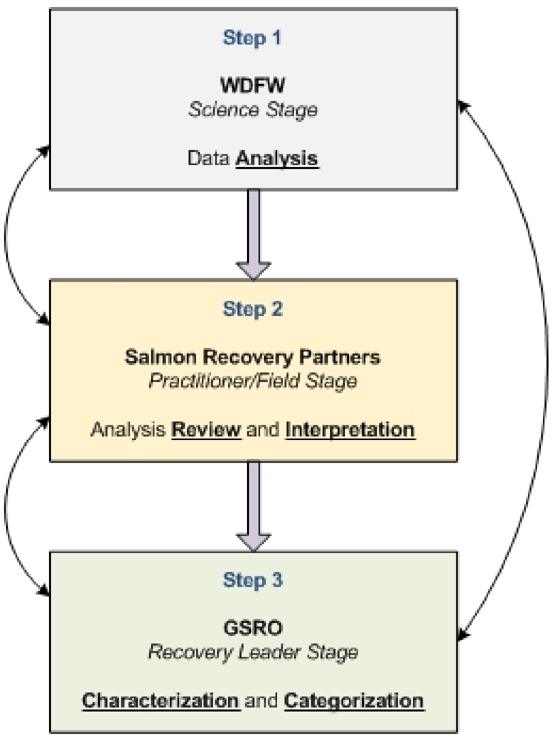
I. Statement of Understanding

The Governor's Salmon Recovery Office (GSRO) is tasked with producing a biennial "State of the Salmon" report. For 2020, WDFW (Fish Science Division) has assisted GSRO with development of a sound body of analytic work to assess adult abundance status and trends in Washington. This body of work is documented consistent with Chart A, Step 1 and 2. This document is WDFW's contribution to Step 1.

Chart A
2020 State of the Salmon Adult Abundance Status and Trends Assessment Process



Click here to access WDFW's ***Status and Trends Analysis of Salmon Abundance Data*** report, including underlying data, analyses, documentation.

Click here to access this document, ***Abundance Analysis Review, Interpretation by Salmon Recovery Partners.***

Click here to access ***Final Adult Abundance Chart***.

For Step 1, it is WDFW's understanding that GSRO desires a quantitative, statistically-sound analysis of available adult abundance data. It is WDFW's further understanding that GSRO desires the analysis use:

- Data that consistently represent NOAA TRT-defined populations and recovery-specific objectives (i.e., natural-origin, naturally-spawning abundance at the Distinct Independent Population (DIP) scale).
- Data that are equivalent across ESUs, DPSs, and populations so adult abundance findings and results can be readily compared.
- An analytic method that is consistent with those used by other salmon recovery organizations (e.g., NOAA, tribal co-managers, and regional recovery organizations).
- An analytic method that is thorough, accurate, and readily reproducible to enable easy updating, and to set the stage for live and continuous updating (i.e., cloud and code-based).
- An analytic method that is collaborative, collegial, and transparent to further spur cross-organization collaboration across salmon recovery partners.

The following report has been prepared consistent with this understanding.

II. Introduction

To assess the status and trends of Washington's salmon and steelhead populations, we adopted an approach that benchmarked populations' abundance against their established recovery goals and estimated their abundance trends using methods like those employed by NOAA Fisheries in its five-year status reviews. While Washington is home to both Endangered Species Act (ESA) listed and non-listed populations, we limited our analysis to ESA-listed Evolutionarily Significant Units (ESU) and Distinct Population Segments (DPS) because of their better described recovery goals and generally higher conservation concerns. Specifically, we used natural-origin spawner abundance data since the year of ESA listing and fit a statistical model that generated smoothed estimates of abundance (including for years with no available data), as well as an estimate of the trend since listing.

The analysis was computed on all populations in an ESU/DPS at once, enabling the model to share information among populations about trends, the strength of correlations among populations in their interannual variability, and the magnitude of signal (red noise) versus random (white) noise in the data. Two metrics (abundance status and trend) were used to assess populations, and the results of these population assessments were summarized at the ESU/DPS-level. To combine status and trend information at the ESU/DPS level for an overall risk assessment, a five-year forward projection was implemented using the current status and the long-term trend.

Methods and data used are based on best available science and consistent with those used by other salmon recovery organizations. Specifically, we used:

- Analytic methods to evaluate population trends comparable to those used by NOAA in their 5-Year Status Reviews.
- The same data as NOAA and tribal co-managers use across the state in these reviews.
- Recovery goals defined by NOAA TRTs.
- Adult abundance population data that match the scale of the recovery goals.

III. Methods

A. Data:

Population abundance recovery goals (Appendix 1) were obtained from recovery plans adopted by NOAA Fisheries. In cases where multiple recovery goals have been adopted, we selected delisting goals, and for stocks with low and high productivity goals, to be more conservative, we selected the low productivity goals since estimating population productivity was beyond the scope of our analysis.

Natural-origin spawner abundance data was obtained from primarily from Coordinated Assessments (CA) and secondarily from the WDFW Salmon Population Indicators database (SPi). Data obtained from Coordinated Assessments were pre-processed to obtain a clean dataset based on the following sequentially executed filters:

1. Data were limited to ESA/DPS-listed populations located partially or entirely in Washington State.

2. Data were limited to those with POPFIT designated as "Same" or "Multiple" in CA, indicating that the population estimate had complete spatial and temporal coverage (as opposed to commonly monitored indexes of abundance, for which comparison with population-level recovery goals is inappropriate).

3. Data were limited to those for which "BESTVALUE" was designated "Yes" indicating that of multiple potential estimates available for that year and population, a particular estimate was the best estimate.

4. A series of population-specific manual filters (seven total) were applied to eliminate duplicate datasets.

5. An algorithm selected the type of data to use for the analysis, looking for datatypes in the following order and stopping when the first data type was found with records: Natural Origin Spawner Abundance Including Jacks, Natural Origin Spawner Abundance Excluding Jacks, Total Spawner Abundance Including Jacks, Total Spawner Abundance Excluding Jacks.

6. A final population-specific manual filter was applied to eliminate datasets for which Total Spawner Abundance was not an appropriate surrogate for Natural Origin Spawner Abundance because the population contained a non-negligible proportion of hatchery spawners.

7. Data were filtered to only include years from ESA listing (which varied by ESU/DPS) through present as our focus was on status and trend since the ESA listing.

B. Model:

A multivariate autoregressive state space random walk with drift (MARSS-RWD) was fit to the log of abundance data for each ESU/DPS. The model structure was identical to that used by NOAA in its 5-year status reviews (NOAA 2015) with a few exceptions:

1. The model was fit to natural-origin spawner data in order to estimate smoothed natural origin spawner abundance and trends. NOAA, in its five-year status review, fit their models to both the log transformed total spawner abundance (including natural- and hatchery-origin spawners) and the logit transformed fraction of natural origin spawners to estimate the smoothed total spawner abundance and the smoothed fraction of natural origin spawners. They multiplied these resulting smoothed estimates by each other to estimate the smoothed natural-origin spawner abundance. Finally, they fit a regression through the resultant smoothed natural origin spawner time series to estimate trends. This method produces nearly identical results if there is no missing data or if the years of missing data are the same for total spawners and the fraction of natural origin spawners. However, if the data series' lengths differ, this method is susceptible to confounding changes in natural-origin spawner abundance with changes in the hatchery-natural origin composition of total spawners, leading to biased conclusions regarding natural-origin spawner status and trends. Populations where changes in the magnitude of hatchery production occurred during the period when total spawner estimates were available, but prior to the initiation of monitoring the fraction of wild spawners, are particularly susceptible to this form of bias. For this reason, we excluded hatchery-origin spawners from our analysis, instead modeling trends in natural origin spawner abundance directly, by only using natural origin spawner data.

2. In NOAA's analysis, the MARSS-RWD estimated each population-specific drift (trend) term independently, implying the a priori belief that trajectories of the populations within an ESU/DPS are entirely independent from one another. We assumed that populations are hierarchically organized and that therefore the long-term trends of populations within an ESU/DPS are partially but not entirely independent of one another due to shared factors influencing their survival. In our model there was an overall ESU/DPS-level trend and each population's trend was the ESU/DPS-level trend plus a normally distributed random deviate. This resulted in a more parsimonious model that better fit the data.

3. In NOAA's analysis, they compared MARSS-RWD models that had either full-rank or extremely reduced-rank process and observation error covariance matrices. Populations either had the same process and observation error variances or completely independent process and observation error variances. They also assumed that the process error correlation matrix was either full rank (all pairwise correlations are independent), uniform (all pairwise correlations are the same), or diagonal (no pairwise correlations), while they assumed a diagonal correlation matrix for observation errors. This approach required fitting a large number of candidate models and only included very parameter rich (e.g., full rank) or very parameter poor (e.g., pooled or diagonal) covariance structures, almost assuring the possibility of overfitting the data or oversimplifying the model and losing information. To address these limitations we: a) performed Cholesky decomposition of the process error covariance matrix, treating the process and observation error variances and the correlation matrix each as random effects within each ESU/DPS, and b) in the absence of a compelling reason to assume that observation errors would be correlated, assumed the observation error covariance matrix was diagonal with the variances treated as random effects.

4. We performed our analysis in a Bayesian Framework using rstan (Gelman 2014), thereby allowing us to obtain full posterior distributions for model parameters rather than maximum likelihood point estimates. By treating key model parameters as random effects we avoided the need to specify priors directly for any population level parameters, instead providing vague

regularizing hyperpriors on ESU/DPS-level random effect variances. We tested our model via simulation and found were unable to detect substantive influence of these prior values on modeled abundances, trends, process error variances and correlations, and other parameters.

Below is detailed description of the model. Note that ESU is used to denote ESU or DPS-level parameters:

1. ***Observation Model:***

The observation model assumed that the observed spawner abundance estimate $N_{y,p}^{observed}$ for each year y and population p was multivariate normally distributed around the smoothed spawner abundance $N_{y,p}^{smoothed}$:

$$\log\left(N_{y,p}^{observed}\right) \sim MVN(\log\left(N_{y,p}^{smoothed}\right), \boldsymbol{\Sigma}_{observation})$$

where the observation error variance-covariance matrix $\Sigma_{observation}$ was a diagonal matrix (no covariance) and was equal to the dot product of a vector of population specific observation error variances and an identity matrix with dimensions equal to the number of populations:

$$\Sigma_{obs} = \sigma^{observation^2} \cdot \boldsymbol{I}$$

The observation error standard deviations were assumed to be half-Cauchy distributed random effects centered around the ESU/DPS-level average observation error standard deviation $\mu_{ESU}^{observation}$. The half-Cauchy distribution was used to allow for a heavier tailed distribution than a normally distributed random effect:

$$\sigma_p^{observation} \sim half - Cauchy(\mu_{ESU}^{observation}, \sigma_{ESU}^{observation})$$

2. ***Process Model:***

The process model assumed the log of smoothed abundance in each year followed a random walk with drift in which the abundance was the sum of the prior year, plus the global trend μ_p plus a process error $w_{y,p}$ representing the annual deviation from the global trend:

$$\log\left(N_{y,p}^{smoothed}\right) = \log\left(N_{y-1,p}^{smoothed}\right) + \mu_p + w_{y,p}$$

The slopes were assumed to be a random effect centered on the ESU/DPS-wide average slope μ_{ESU}^{slope}:

$$\mu_p \sim Normal(\mu_{ESU}^{slope}, \sigma_{slope})$$

The process errors were assumed to be multivariate normally distributed:

$$w_{y,p} \sim MVN(0, \Sigma_{process})$$

The process error variance-covariance matrix was decomposed via Cholesky decomposition into a lower-left triangular matrix $L_{process}$, the elements of which were the among-population process error correlations, and a diagonal matrix $D_{process}$, the elements of which were the process error variances $\sigma_p^{process}$.

$$\Sigma_{process} = D_{process}\, L_{process}\, L_{process}{}' D_{process}$$

The process error standard deviations were assumed to be half-Cauchy distributed random effects centered around the ESU/DPS-level average process error standard deviation $\mu_{\mathrm{ESU}}^{\mathrm{process}}$. The half-Cauchy distribution was used to allow for greater dispersion than a normal random effect:

$$\sigma_p^{process} \sim half - Cauchy(\mu_{ESU}^{process}, \sigma_{ESU}^{process})$$

3. ***Priors:***

The first state of smoothed abundance for each population was given a vague empirical Bayes prior centered on observed abundance from the first year or, if there was no observation in that year, the observation from the nearest year:

$$\log\left(N_{y=1,p}^{smoothed}\right) \sim Normal(\log\left(N_{\min(y),p}^{observed}\right), 2)$$

The average ESU/DPS-wide trend slope was given a vague normal prior centered on zero:

$$\mu_{ESU}^{slope} \sim Normal(0,0.25)$$

The standard deviation in trends across the ESU/DPS was given a vague half-Cauchy prior:

$$\sigma_{slope} \sim half - Cauchy(0,0.1)$$

The ESU/DPS-wide mean process and observation error standard deviations were both given vague boundary-avoiding inverse gamma priors, which prevented the model from allowing either to be exactly zero:

$$\mu_{ESU}^{observation} \sim inverse\ gamma(1,0.125)$$
$$\mu_{ESU}^{process} \sim inverse\ gamma(1,0.125)$$

The ESU/DPS -wide standard deviations governing among-population variability in population-level process and observation error standard deviations were given a vague half-Cauchy priors:

$$\sigma_{ESU}^{observation} \sim half - Cauchy(0,0.1)$$
$$\sigma_{ESU}^{process} \sim half - Cauchy(0,0.1)$$

The lower left triangular correlation matrix was given an LKJ prior with shape parameter equal to one, which provides for a uniform prior on the pairwise correlations within their identifiable parameter space (Barnard et al., 2000):

$$L_{process} \sim \mathrm{LKJ}(1)$$

4. ***Summary Statistics:***

We used two key model outputs to summarize population status and trends: the five-year geomean of the smoothed abundance divided by the recovery goal:

$$5\ year\ Geomean\ \%\ of\ Recovery\ Goal = 100 \cdot \frac{e^{\frac{\sum_{y=2015}^{y=2019} \log\left(N_{y,p}^{smoothed}\right)}{5}}}{Recovery\ Goal}$$

and the trend since ESA listing expressed as a percent change per year:

$$Percent\ Change\ Per\ Year = 100 \cdot (e^{\mu_p} - 1)$$

Although the status (recovery ratio) and trends (percent change per year) of populations within an ESU/DPS were variable, because recovery plans depend on recovering individual populations rather than averaging ESU/DPS performance across populations, we used the median status and trend (among populations) as a measure of central tendency to assess performance at the ESU/DPS level. Status relative to recovery goals was deemed to be the most important measure of performance. However, from a risk perspective, current status alone ignores trends. Therefore, to incorporate trend information in establishing overall ESU/DPS risk, we projected each ESU/DPS's future status by applying its median trend since ESA/DPS -listing to its current status (median of population level five-year geomean % of recovery goal):

$$Future\ ESU/\text{DPS}\ Status\ (\%\ of\ Recovery\ Goal) =$$
$$Median(5\ year\ Geomean\ \%\ of\ Recovery\ Goal) \cdot (1 + Median(\%\ change\ per\ year))^5$$

While there are far more sophisticated ways to project population status into the future (Buhle et al., 2018), this coarse method allowed us to generate a straightforward, easily calculated metric for categorizing overall ESU/DPS risk as a function of current status and trends. Our logic in choosing a five-year horizon is the following. If one only considers current status, then trends do not have any influence on the assessment. This could lead to focusing equally on populations with the same status but opposite trajectories. If one chooses a very long (e.g., 100 years) time horizon, even with very modest growth rates, current status becomes irrelevant; growing populations become very large and shrinking populations will near extinction regardless of their starting points due to the power of compounding growth rates. A five-year time horizon was chosen because ESU/DPS-level performance was still primarily driven by current status and because a five-year time horizon matches the ESA status review timeline and is a useful timeline for prioritizing, planning, and implementing recovery actions.

5. ***Criteria for Inclusion of a Population or ESU/DPS in Summary Statistics:***

   a. Populations were included if:

      - They had a recovery goal identified in a federally-adopted recovery plan.

      - They had at least one year of usable natural-origin spawner abundance data, which required that:

- the population had an abundance monitoring program at least at some point since ESA-listing
- abundance estimation occurred at the NOAA-designated population-spatial scale (not only a sub-component)
- abundance estimates either included negligible hatchery fish (i.e., essentially not believed to be present), or abundance estimation including estimating the proportion of hatchery fish so the natural origin abundance could be separated from the total, and
- abundance estimates were reported correctly in the Coordinated Assessments or SPi databases.

b. ESUs/DPSs were included if they had at least one population that had at least one data point from the 5-year period for which geomeans were calculated (2015-2019).

c. Populations/ESUs/DPSs without recovery goals were completely omitted from the analysis (e.g., White River Spring Chinook).

IV. Results

A. Data availability (Figure 1 below)

Usable ESA-listed salmon and steelhead adult abundance data for our assessment were available from all 14 ESUs/DPSs, but not for all years or populations. Of the 147 defined populations, 134 had defined recovery goals (91%) and 98 had usable abundance datasets (66.7%). All ESUs/DPSs had at least one population for which data has been collected in the most recent five-year period. The percent of populations with at least one year of usable data within a given ESU/DPS ranged from a low of 40% (for Columbia River Chum ESU and Puget Sound Steelhead DPS) to a high of 100% (Snake River Fall Chinook ESU, Snake River Spring/Summer Chinook ESU, Upper Columbia River Spring, Chinook ESU, Hood Canal Summer Chum ESU, Ozette Lake Sockeye ESU, Snake River Basin Steelhead DPS, and Upper Columbia River Steelhead DPS).

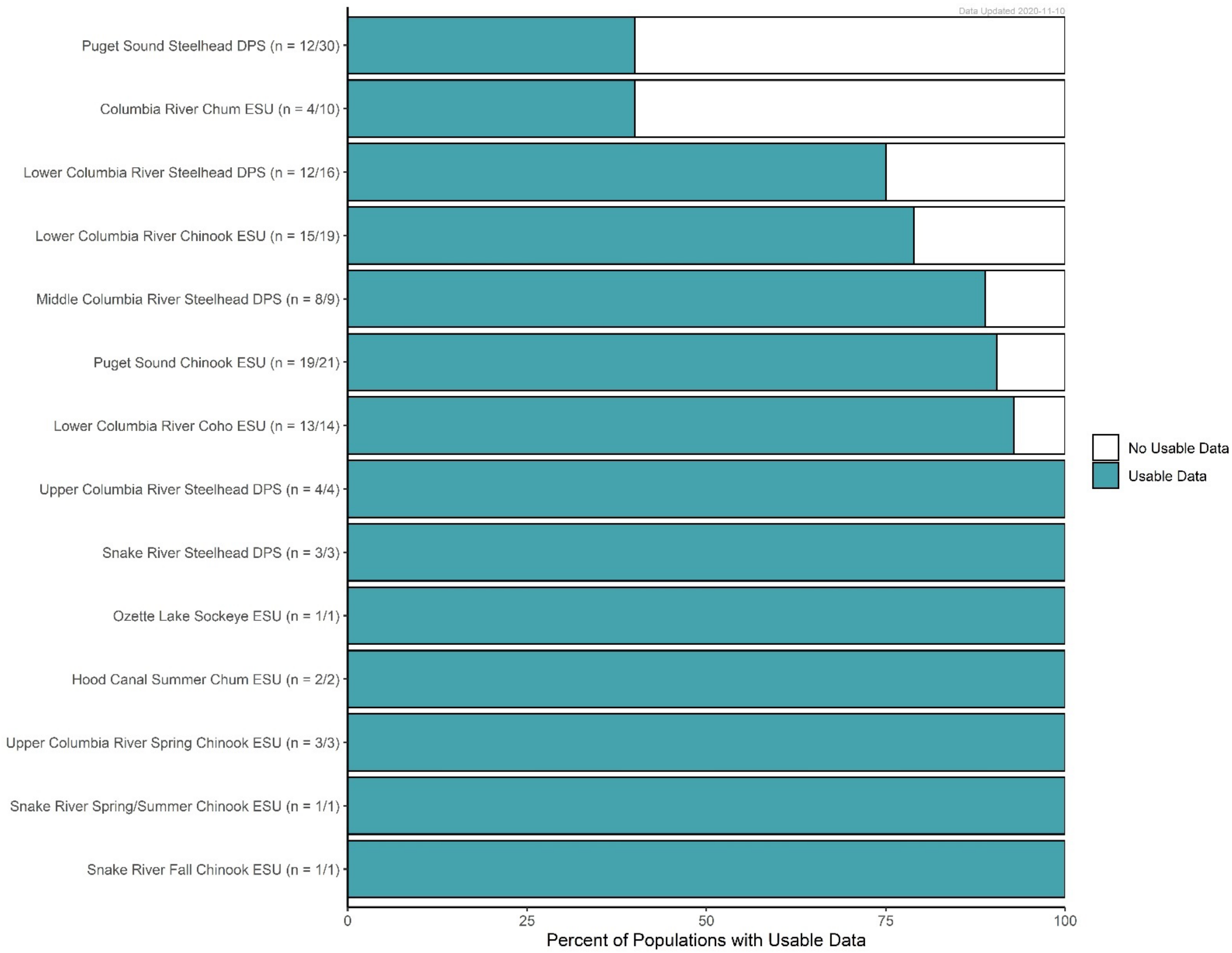


Figure 1. *The percent of ESA-listed salmon and steelhead populations with at least one year of usable adult abundance data by ESU/DPS. The number of populations with usable data out of the total number of populations in the ESU/DPS is listed in parentheses. Populations with no recovery goals are excluded.*

B. Abundance Status and Trends (Figures 2 and 3 below)

1. ***Status:*** The abundance status of populations was assessed by dividing the most recent five-year (2015-2019) geomean of the smoothed adult abundance by the recovery goal. At the ESU/DPS scale, abundance status was less than 100% for greater than 50% of populations, and the abundance status of the median population was below 100% in 10 of the 14 ESUs/DPSs (Figures 2 and 3). Seven of these ESUs/DPSs had no populations with abundance above their recovery goals whereas five ESUs/DPSs had at least one population with abundance above its recovery goal. Of the two ESUs/DPS with an average adult abundance status of greater than 100%, both contained populations far from their recovery goals in addition to populations well above their goals (Figures 2 and 3).

2. ***Trends:*** Of the 14 ESUs and DPSs, the average adult abundance trend since ESA listing expressed as a percent change per year was lowest for Snake River Basin Steelhead DPS (-7.3%) and highest for Hood Canal Summer Chum ESU (9.5%) (Figures 2 and 3). Across all ESUs/DPSs, the average percent change per year was -1.0%. All populations have a negative percent change in six ESUs/DPS whereas all populations' percent changes were positive in seven ESUs/DPSs. Therefore, only 1 ESU/DPS (Middle Columbia River Steelhead) had populations with both negative and positive change values (Figures 2 and 3). This suggested similarities in abundance trends among populations with an ESU/DPS.

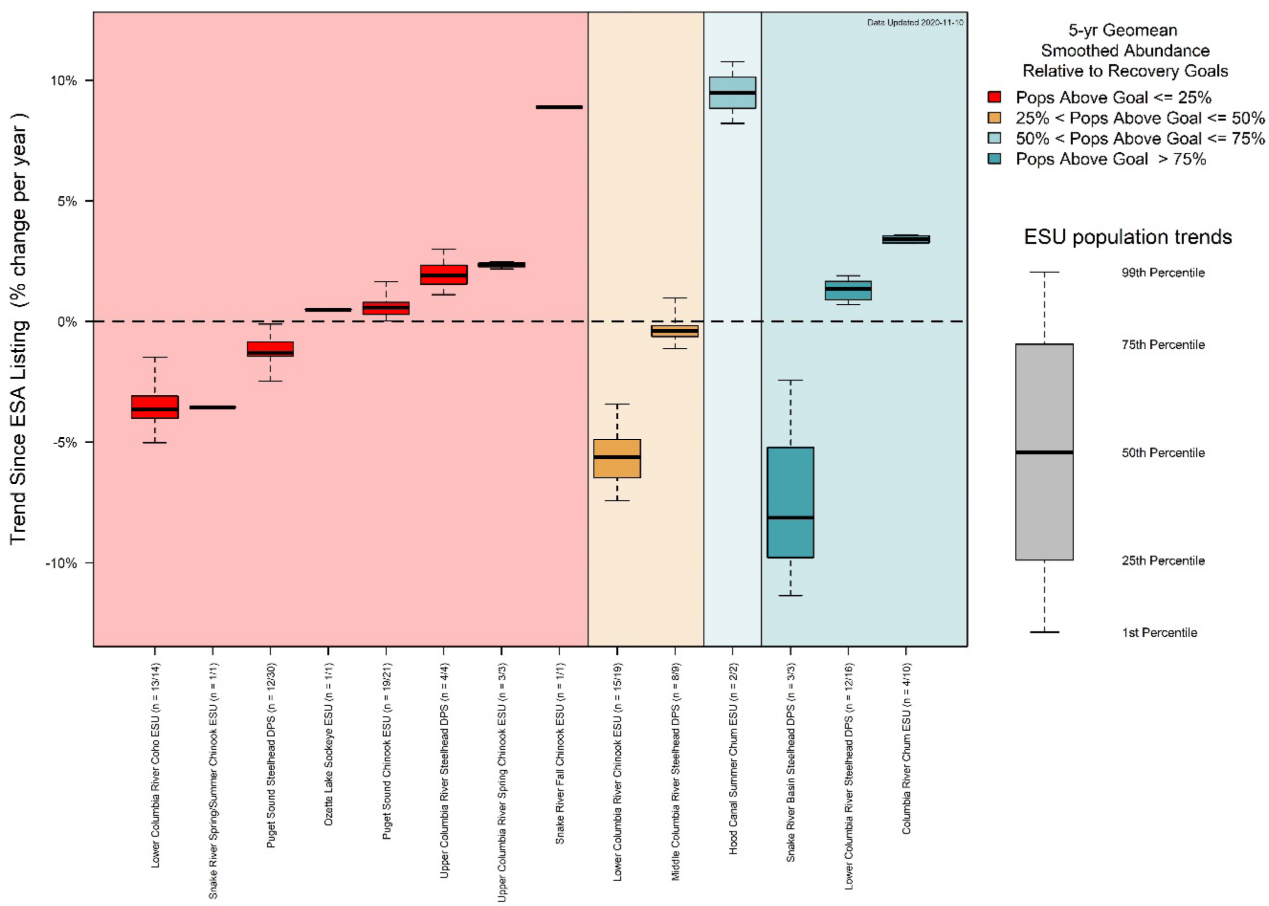
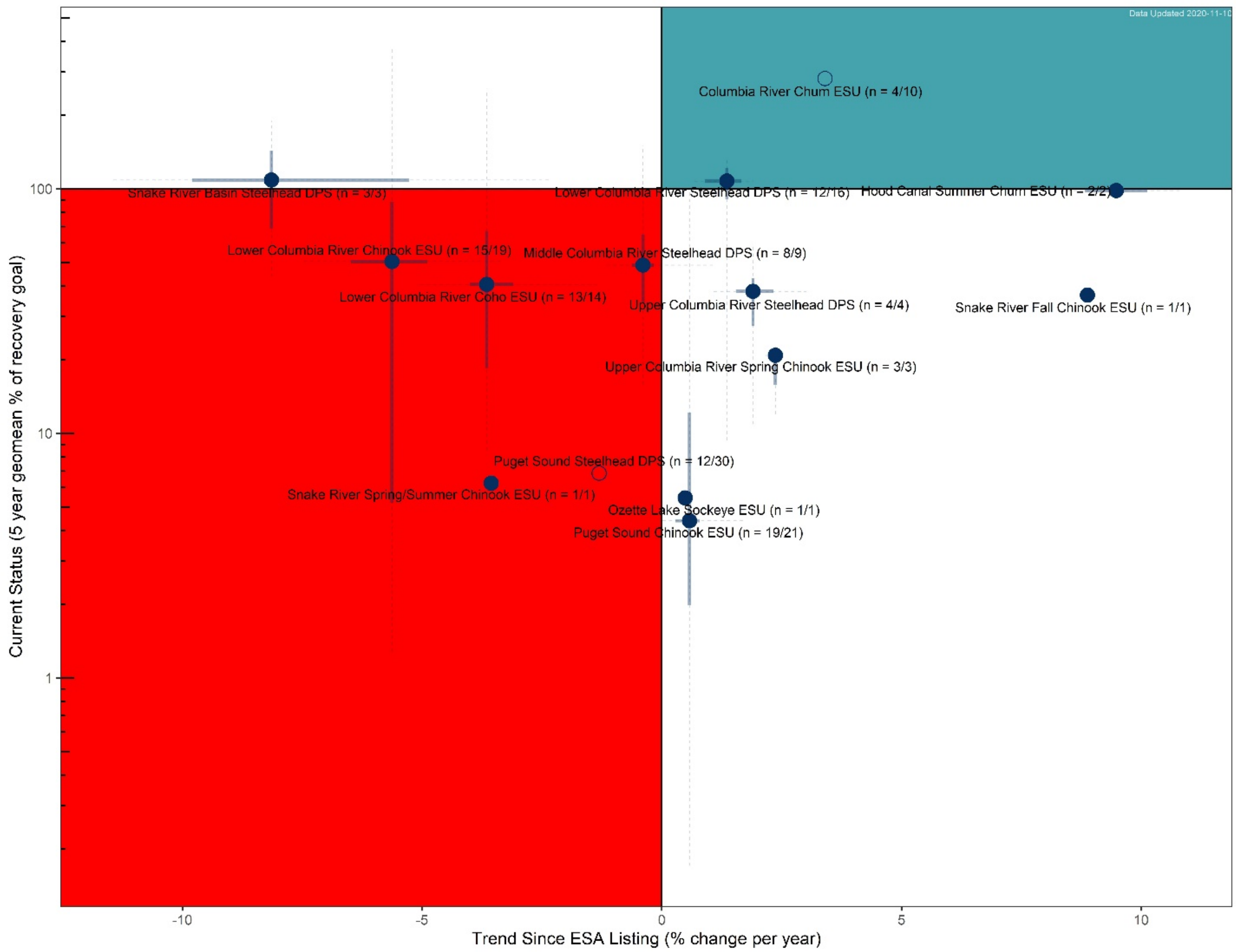


Figure 2. *Categorical status and trend by ESU/DPS. Box and whisker plots display the median (thick horizontal line), interquartile (box), and lowest and highest (whiskers) population-level trends since listing within an ESU/DPS. ESU/DPS status is divided into four colored bins based on the percent of populations with 5-year geomean smoothed abundance ≥ the recovery goal. Within*

each bin, ESU/DPSs are sorted based on their median population-level trend since listing. The number of populations with usable data out of the total number of populations in the ESU/DPS is listed in parentheses. Populations with no recovery goals are excluded.



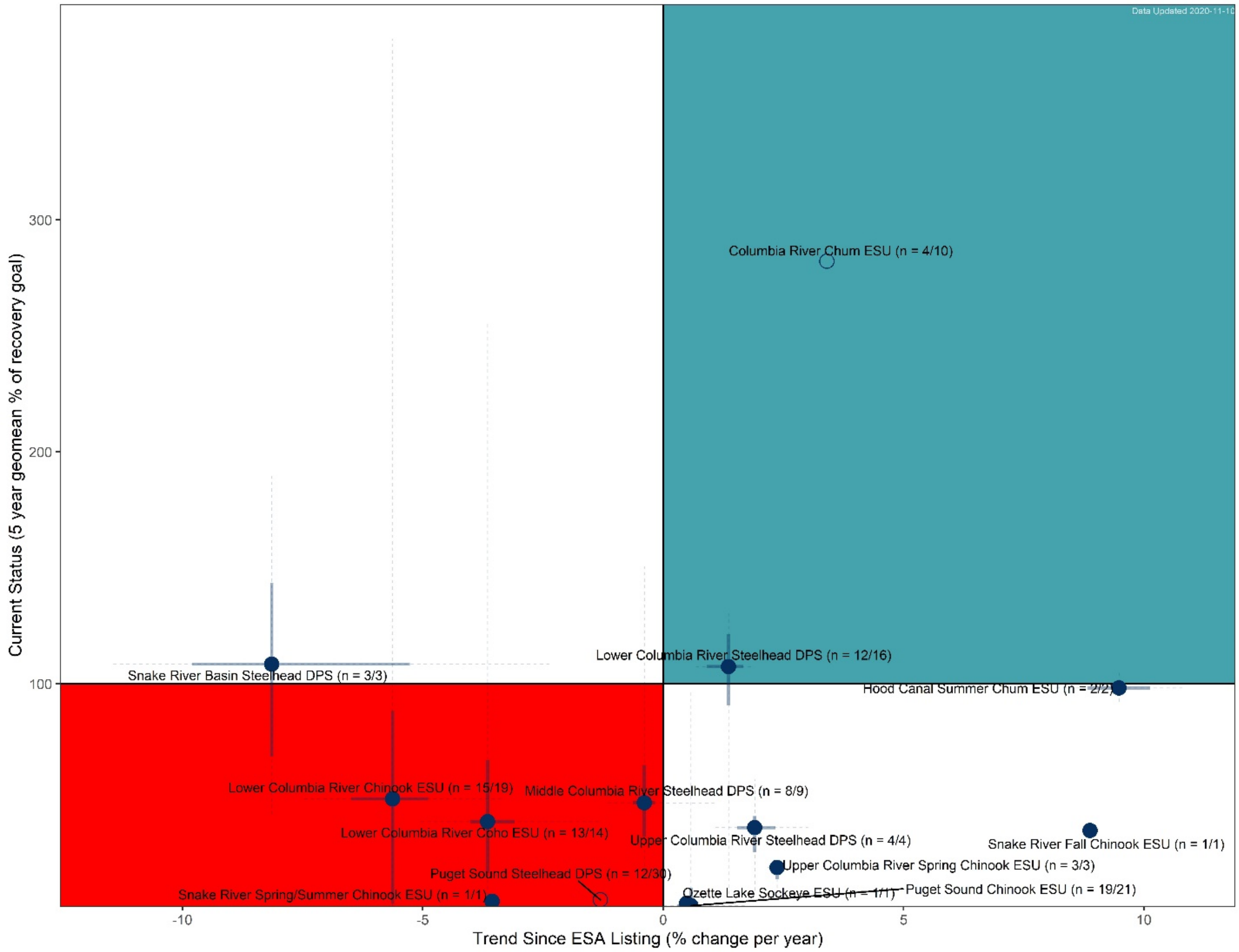
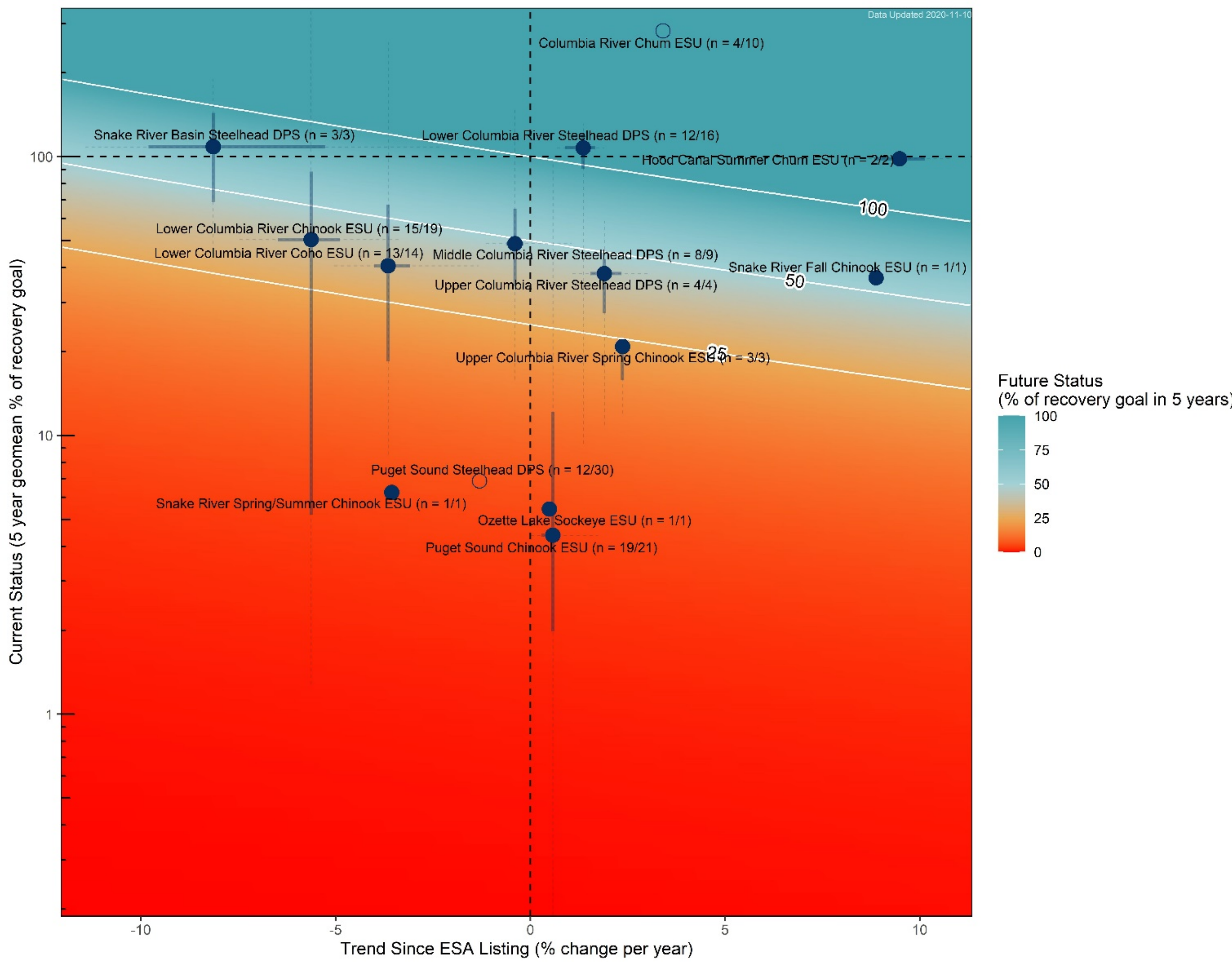


Figure 3. Continuous abundance status and trend by ESU/DPS. *[Top Panel: y-axis is log10 transformed; Bottom Panel: y-axis is not log10 scaled.] Points for each ESU/DPS represent the median population-level abundance trend (% change per year) since listing and the median population-level five-year abundance geomean percent of recovery goal. Thick lines are the interquartile range of population-level statuses and trends within an ESU/DPS, while dotted lines show the highest and lowest status and trend outlier populations within the ESU/DPS. Background colors in the plot quadrants denote ESU/DPS risk levels (red = declining trend and below recovery goal, teal = increasing status and above recovery goal, white = increasing trend and below recovery goal or decreasing trend and above recovery goal). The number of populations with usable data out of the total number of populations in the ESU/DPS is listed in parentheses. Populations with no recovery goals are excluded from these counts. ESU/DPSs with more than 40% of populations missing data are plotted as empty circles and lines showing interquartile ranges and extremes are not plotted, reflecting the considerable uncertainty in the status and trend of these ESU/DPSs.*

3. **<u>Future Abundance Status and Overall Risk Categorization (Figure 4 below):</u>** Finally, the future status assessment showed that several ESU/DPSs (5 of 14; 36%) were in the < 25% future status (% of recovery goal in 5 years) category (Figure 4, Table 5) and the 25-50% future status (4 of 14; 29%). Two ESU/DPSs (Snake River Fall Chinook ESU and Snake River Basin Steelhead DPS) were in the 50-100% future status range, and three ESU/DPSs (Hood Canal Summer Chum ESU, Lower Columbia River Steelhead DPS, and Columbia River Chum ESU) were in the >100% status (Figure 4). This suggests that while only two ESU/DPSs have a recent 5-year geomean at > 100%, two more of them are expected to be above 100% in 5 years due to

their positive trends. Based only on these numerical ranges of projected future abundance status, we assigned a preliminary recovery category to each ESU (Table 1). Care should be taken in interpreting placement of Columbia Chum ESU and Puget Sound Steelhead DPS due to low data availability (Table 1.)



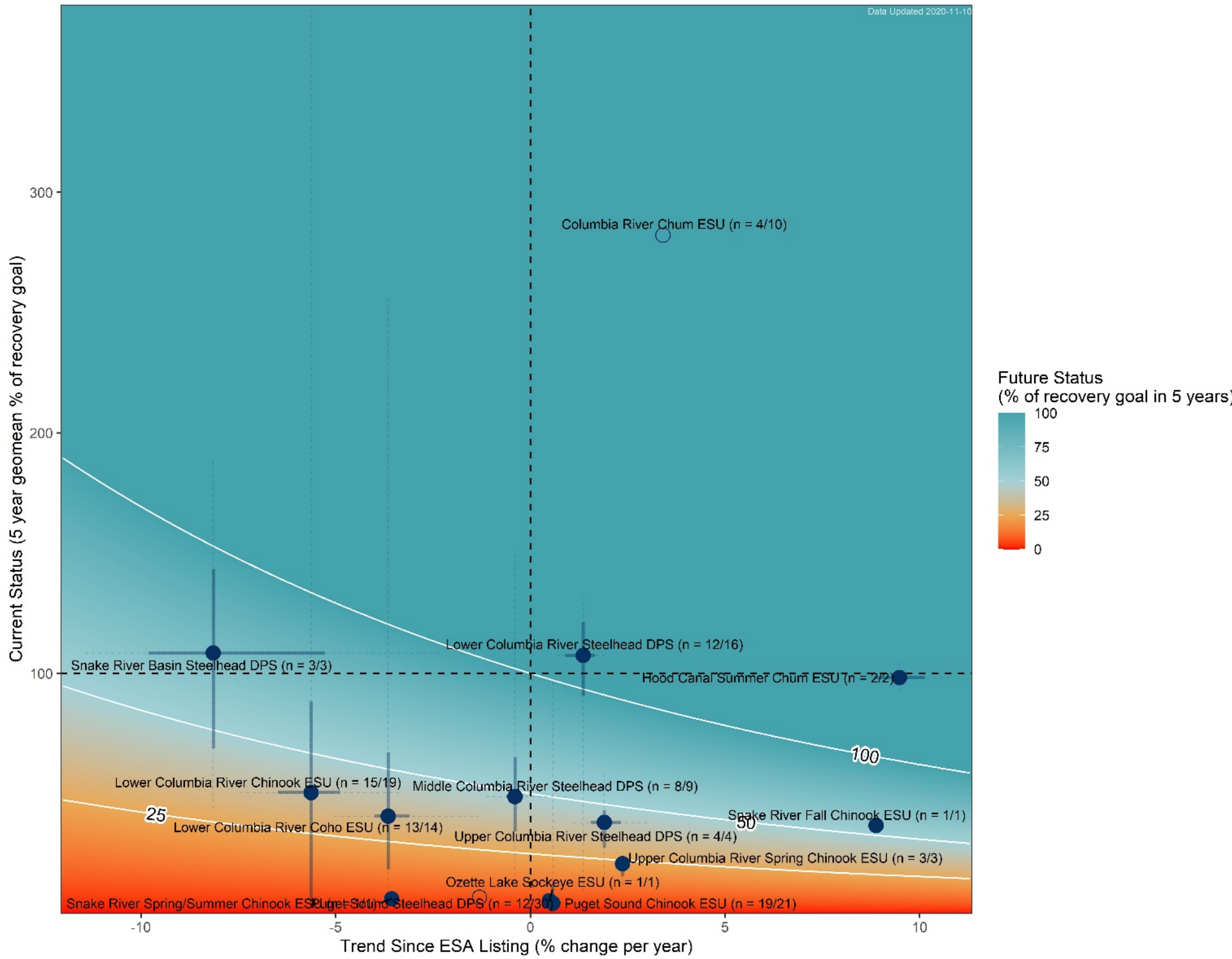


Figure 4. Abundance status and trend by ESU/DPS with future status contours. *[Top Panel: y-axis is log10 transformed; Bottom Panel: y-axis is not log10 scaled.] This plot displays points for each ESU/DPS representing the median population-level abundance trend (% change per year) since listing and the median population-level five-year abundance geomean percent of recovery goal. Thick lines are the interquartile range of population-level statuses and trends within an ESU/DPS, while dotted lines show the highest and lowest status and trend outliers within the ESU/DPS. Background color contours and isoclines denote the future status of ESU/DPSs as percentage of their recovery goals in five years, as projected based on current status and trends denoted by the dot (see methods). The number of populations with usable data out of the total number of populations in the ESU/DPS is listed in parentheses. Populations with no recovery goals are excluded from these counts. ESU/DPSs with more than 40% of populations missing data are plotted as empty circles and lines showing interquartile ranges and extremes are not plotted, reflecting the considerable uncertainty in the status and trend of these ESU/DPSs.*

V. Discussion

Following quantitative development of findings, results, and charts, individual ESU and DPS populations were assigned and categorized to the following table (Table 1) as the end product of the Step 1 analysis.

Table 1. Risk categorization of ESUs and DPSs based on 5-yr future projected status using current status and trend since ESA listing.

In Crisis (Future Status < 25% of recovery goal)	*Not Keeping Pace (25% < Future Status <50% of recovery goal)*	*Making Progress (50% < Future Status <100% of recovery goal)*	*Approaching Goal (Future Status > 100% of recovery goal)*
Upper Columbia River Spring Chinook	**Middle Columbia River Steelhead**	**Snake River Basin Steelhead**	**Lower Columbia River Steelhead**
Puget Sound Chinook	**Lower Columbia River Coho**	**Snake River Fall Chinook**	**Hood Canal Summer Chum**
Snake River Spring/Summer Chinook	**Lower Columbia River Chinook**		**Columbia River Chum***
Lake Ozette Sockeye	**Upper Columbia River Steelhead**		
Puget Sound Steelhead*			

*Chart placement for these ESUs is uncertain due to >40% of populations lacking sufficient data for assessment.

Step 2 documents review perspectives from salmon recovery partners, practitioners, and those in the field, and is available here.

Data and analysis caveats:

- ***Status results are relative to recovery goals, rather than absolute conservation status --*** Assessments of population and ESU/DPS-level status relied on comparing smoothed abundance to recovery goals. This enabled comparison of populations and ESUs/DPSs based on the five-year geomean % of recovery goals. However, very different methods were used by NOAA Fisheries and local entities to establish recovery goals various ESUs/DPSs, meaning that a particular geomean percent of a recovery goal may represent different levels of conservation risk in different ESUs/DPSs.

- ***Missing data may not be random --*** Results presented are only an accurate representation of status and trends if the data used are representative of the ESUs/DPSs. If populations with missing data have systematically different status and trends than those analyzed, ESU/DPS-level conclusions may be biased. For example, although the Lower Columbia Chum ESU status appears very good, this is a result of monitoring programs only existing in watersheds with the largest and healthiest populations; most other populations exist at very small abundances with few or no spawners seen in many years. A lack of usable data on these populations clearly leads to biased conclusions in this case.

- ***Comparison with NOAA 5-year status review*** **--** While methods used herein to estimated smoothed abundance and trends since listing are broadly similar to those used by NOAA, several important differences exist that make these results not perfectly comparable to theirs. First, there are small analytical differences in the model used (see Methods). Second, data retrieval for this analysis and NOAA status reviews is not yet fully automated, leading to inevitable differences in underlying data. Third, our analysis is limited to the portions of ESUs/DPSs within Washington State, affects conclusions regarding ESUs/DPSs that include populations in other states. Finally, overall ESA status assessments, let alone delisting decisions, are a function of more than just the status and trends of salmonid abundance and is ultimately under NOAA's jurisdiction.

- ***Population list*** **--** The total number of populations available for reporting in each ESU/DPS may differ from the total reported by NOAA, not only because populations outside of Washington State and those lacking recovery goals were excluded, but also because some populations have abundance data which are monitored (and thus modelled) in combination. For example, Upper Cowlitz River winter steelhead are monitored in combination with Cispus River winter steelhead and therefore only one population is counted in the set of possible populations for the Lower Columbia River Steelhead DPS (Upper Cowlitz winter steelhead) and the recovery goal for the two is also combined (summed) in order to match the spatial scale of monitoring and status and trend assessment.

VI. References

- Barnard, John, Robert McCulloch, and Xiao-Li Meng. 2000. Modeling Covariance Matrices in Terms of Standard Deviations and Correlations, with Application to Shrinkage. Statistica Sinica, 1281–1311.

- Buhle, E. R., M. D. Scheuerell, T. D. Cooney, M. J. Ford, R. W. Zabel, and J. T. Thorson. 2018. Using Integrated Population Models to Evaluate Fishery and Environmental Impacts on Pacific Salmon Viability. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-140. DOI: 10.7289/V5/TMNWFSC-14 https://www.webapps.nwfsc.noaa.gov/assets/25/9397_05222018_110900_TechMemo140.pdf

- Gelman, A. 2014. RStan: the R interface to Stan. R Package Version, 2, 1–22.

- Northwest Fisheries Science Center. 2015. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Pacific Northwest. https://www.webapps.nwfsc.noaa.gov/assets/11/8623_03072016_124156_Ford-NWSalmonBioStatusReviewUpdate-Dec%2021-2015%20v2.pdf

VII. Data Sources

- Salmon Conservation and Reporting Engine (SCoRE) -- https://fortress.wa.gov/dfw/score/score/species/species.jsp

- Coordinated Assessments Indicators of Fish Population Health (CA) -- https://cax.streamnet.org/

VIII. Data, Analysis Results, Comparison Charts, and Other Documentation

All data sources, results, charts, and other documentation used by WDFW in this analysis to produce a sound body of analytic material to assess adult abundance status and trends has been posted to data.wa.gov. See https://data.wa.gov/browse?q=WDFW%20SDFP&sortBy=last_modified&utf8=%E2%9C%93. This material is additionally presented below as of the date of this report (i.e., 12/04/2020).

Data: Analysis data include, when available, natural-origin, naturally-spawning salmon, and steelhead abundance data (numbers of adults) for each Distinct Independent Population (DIP). For some populations, naturally-spawning abundance data may have been used when origin information (hatchery vs. natural) was not available. Recovery goals (numbers of adults) were obtained from NOAA Technical Recovery Team (TRT) documents and are population specific. For some populations (e.g., Puget Sound Chinook), low and high productivity recovery goals were produced, and we used the low productivity goals to be more conservative, since estimating population productivity was beyond the scope of our analysis.	
1. Analysis Data	https://data.wa.gov/dataset/Analysis-Data/nfcx-sbny
2. Recovery Goals	https://data.wa.gov/dataset/Recovery-Goals/dpm3-4juy

Individual Analysis Results: Abundance data, modeled abundance data, and model results at the population and ESU/DPS scale.	
3. DIP Results	https://data.wa.gov/dataset/DIP-Results/bjxq-pvgg
4. Smoothed Abundance	https://data.wa.gov/dataset/Smoothed-Abundance/ku3c-bpyf
5. Lower Columbia River Chinook ESU	https://data.wa.gov/dataset/Lower-Columbia-River-Chinook-ESU/3jzv-2592
6. Puget Sound Chinook ESU	https://data.wa.gov/dataset/Puget-Sound-Chinook-ESU/7siw-ipvy
7. Snake River Fall Chinook ESU	https://data.wa.gov/dataset/Snake-River-Fall-Chinook-ESU/i8h6-ha8i
8. Snake River Spring and Summer Chinook ESU	https://data.wa.gov/dataset/Snake-River-Spring-and-Summer-Chinook-ESU/yaum-5pxn

9. Upper Columbia River Spring Chinook ESU	https://data.wa.gov/dataset/Upper-Columbia-River-Spring-Chinook-ESU/bams-82px
10. Columbia River Chum ESU	https://data.wa.gov/dataset/Columbia-River-Chum-ESU/hwwg-vsug
11. Hood Canal Summer Chum ESU	https://data.wa.gov/dataset/Hood-Canal-Summer-Chum-ESU/n25s-2gfv
12. Lower Columbia River Coho ESU	https://data.wa.gov/dataset/Lower-Columbia-River-Coho-ESU/gbf6-g848
13. Ozette Lake Sockeye ESU	https://data.wa.gov/dataset/Ozette-Lake-Sockeye-ESU/rd2t-k8at
14. Lower Columbia River Steelhead DPS	https://data.wa.gov/dataset/Lower-Columbia-River-Steelhead-DPS/r7i3-n9ww
15. Middle Columbia River Steelhead DPS	https://data.wa.gov/dataset/Middle-Columbia-Steelhead-DPS/jss9-5bsp
16. Puget Sound Steelhead DPS	https://data.wa.gov/dataset/Puget-Sound-Steelhead-DPS/jkih-wqns
17. Snake River Basin Steelhead DPS	https://data.wa.gov/dataset/Snake-River-Basin-Steelhead-DPS/nvwb-gsip
18. Upper Columbia Steelhead DPS	https://data.wa.gov/dataset/Upper-Columbia-Steelhead-DPS/8ucq-qtbx

ESU/DPS Results: Information about abundance data availability, abundance trends, comparison of abundance to recovery goals, and future status projections across all populations within each ESU/DPS.	
19. ESU-DPS Results	https://data.wa.gov/dataset/ESU-DPS-Results/wmi9-irxa
20. Figure 1 – Abundance Data Availability	https://data.wa.gov/Natural-Resources-Environment/Figure-1-Abundance-Data-Availability/ezjy-9add
21. Figure 2 -- Categorical Status and Trend By ESU-DPS	https://data.wa.gov/Natural-Resources-Environment/Figure-2-Categorical-Status-and-Trend-By-ESU-DPS/q28u-gfg9

22. Figure 3 -- Continuous Abundance Status and Trend By ESU-DPS	https://data.wa.gov/Natural-Resources-Environment/Figure-3-Continuous-Abundance-Status-and-Trend-By-/94yr-7wu3
23. Figure 4 -- Continuous Abundance Status and Trend By ESU-DPS With Future Status Contours	https://data.wa.gov/Natural-Resources-Environment/Figure-4-Continuous-Abundance-Status-and-Trend-By-/rcec-xuv3

Other Documentation: Reports, communications, summary analyses, and the data for web charts.	
24. Step 1 -- Status and Trends Analysis of Salmon Abundance Data Report	https://data.wa.gov/dataset/WDFW-Status-and-Trends-Analysis-of-Salmon-Abundanc/fs39-yvqy
25. Step 2 – WDFW Abundance Analysis Review Comments	https://data.wa.gov/Natural-Resources-Environment/WDFW-Abundance-Analysis-Review-Comments/rmp5-ihun
26. Overview -- Status and Trends Analysis of Salmon Abundance Data Key Links	https://data.wa.gov/dataset/Status-and-Trends-Analysis-of-Salmon-Abundance-Dat/7xsn-jhyc
27. Data for 2020 SOS Web Charts -- Adult Abundance Escapement Data (2020 SOS) ["abundance_quantity"]	https://data.wa.gov/dataset/Adult-Abundance-Escapement-Data-2020-SOS-/ivpk-yg37
28. Data for 2020 SOS Web Charts -- Adult Abundance Escapement Data (2020 SOS) ["abundance_qty"]	https://data.wa.gov/Natural-Resources-Environment/Adult-Abundance-Escapement-Data-2020-SOS-abundance/rmgn-qkw3
29. Data for 2020 SOS Web Charts -- Adult Abundance Recovery Goals (2020 SOS)	https://data.wa.gov/dataset/Adult-Abundance-Recovery-Goals-2020-SOS-/e3x6-7wqn
30. Data for 2020 SOS Web Charts -- Adult Abundance Population Data (2020 SOS)	https://data.wa.gov/dataset/Adult-Abundance-Population-Data-2020-SOS-/9yby-x59c

IX. Contact

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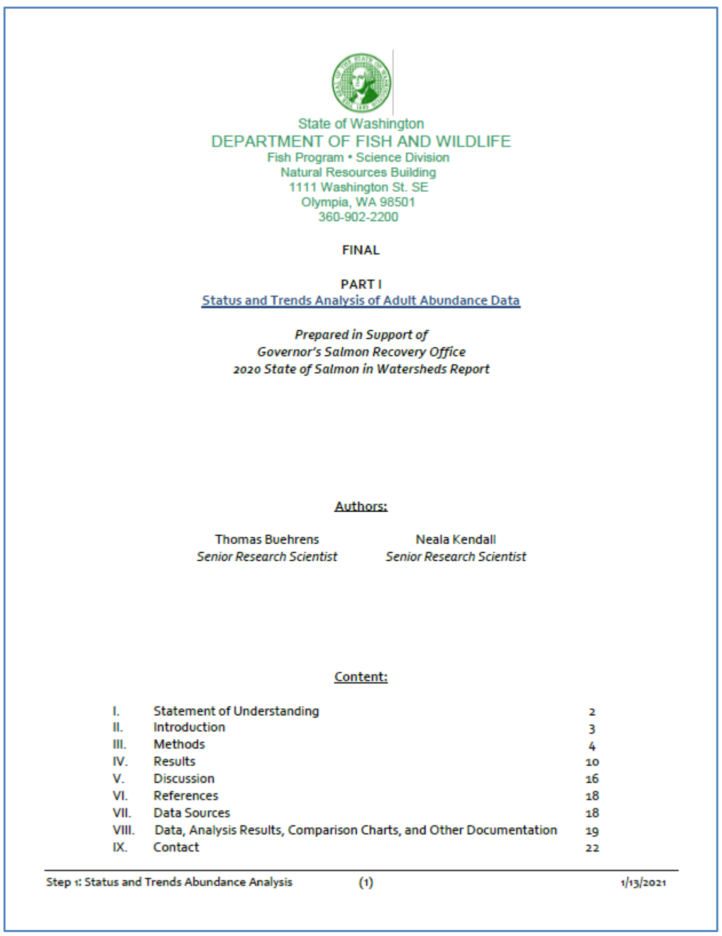
FINAL

PART II

Adult Abundance Analysis Review, Interpretation by Salmon Recovery Partners



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PART I
Status and Trends Analysis of Adult Abundance Data

Prepared in Support of
Governor's Salmon Recovery Office
2020 State of Salmon in Watersheds Report

Authors:

Thomas Buehrens, *Senior Research Scientist*
Neala Kendall, *Senior Research Scientist*

Content:

Step 1: Status and Trends Abundance Analysis (1) 1/13/2021

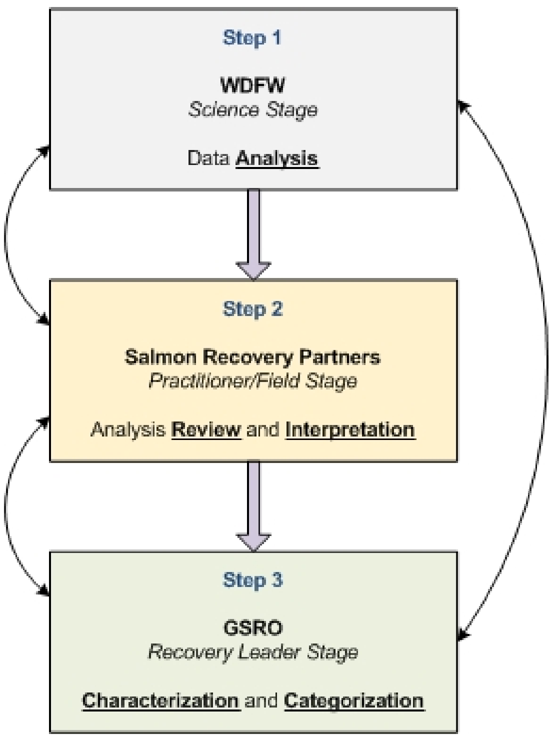
Content:

I. Introduction

The Governor's Salmon Recovery Office (GSRO) is tasked with producing a biennial "State of the Salmon" report. For 2020, WDFW (Fish Science Division) has assisted GSRO with development of a sound body of analytic work to assess adult abundance status and trends in Washington. This body of work is documented consistent with Chart A, Step 1 and 2. This document is WDFW's contribution to Step 2.

Chart A

2020 State of the Salmon Adult Abundance Status and Trends Assessment Process



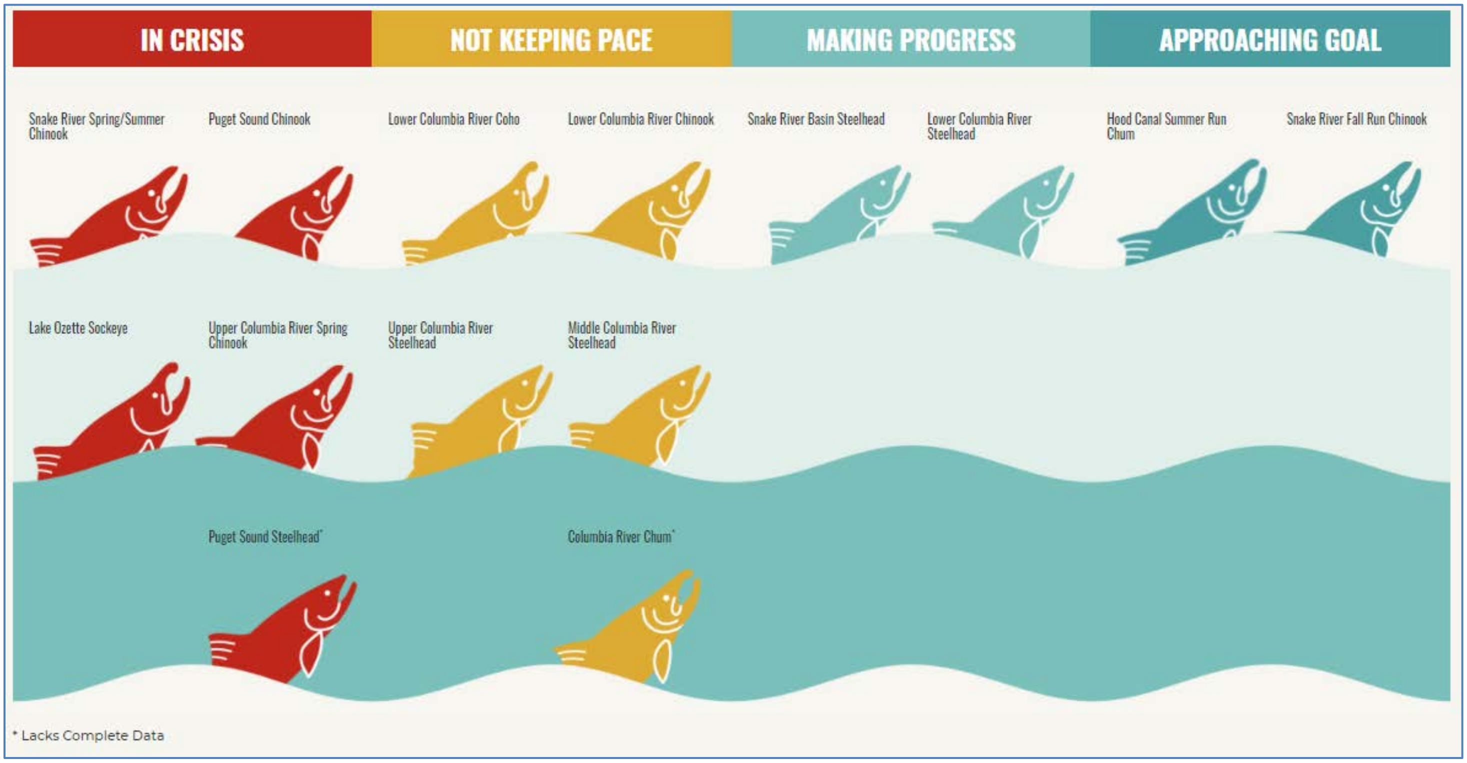
Click here to access WDFW's ***Status and Trends Analysis of Salmon Abundance Data*** report, including underlying data, analyses, documentation.

Click here to access this document, ***Abundance Analysis Review, Interpretation by Salmon Recovery Partners.***

Click here to access ***Final Adult Abundance Chart***.

II. Comparison -- Similarities/Differences

Final **Adult Abundance Chart** (Step 3) for GSRO's 2020 State of the Salmon in Watersheds report/website is as follows:



The following similarities and differences were noted between WDFW's analysis of available abundance data and GSRO's final chart:

ESU/DPS	Initial Placement (Step 1)	Final Placement (Step 3)	
Puget Sound Chinook	In Crisis	In Crisis	✓
Snake River Spring and Summer Chinook	In Crisis	In Crisis	✓
Upper Columbia River Spring Chinook	In Crisis	In Crisis	✓
Ozette Lake Sockeye	In Crisis	In Crisis	✓
Puget Sound Steelhead	In Crisis	In Crisis	✓
Lower Columbia River Chinook	Not Keeping Pace	Not Keeping Pace	✓
Lower Columbia River Coho	Not Keeping Pace	Not Keeping Pace	✓
Middle Columbia River Steelhead	Not Keeping Pace	Not Keeping Pace	✓
Upper Columbia Steelhead DPS	Not Keeping Pace	Not Keeping Pace	✓
Snake River Basin Steelhead DPS	Making Progress	Making Progress	✓
Hood Canal Summer Chum	Approaching Goal	Approaching Goal	✓
Snake River Fall Chinook	**Making Progress**	**Approaching Goal**	**X**
Columbia River Chum	**Approaching Goal**	**Not Keeping Pace**	**X**
Lower Columbia River Steelhead	**Approaching Goal**	**Making Progress**	**X**

III. WDFW -- Perspective on Differences

ESU/DPS	Initial Placement (Step 1)	Final Placement (Step 3)	WDFW Perspective
Snake River Fall Chinook	Making Progress	Approaching Goal	WDFW does not entirely agree with this final placement. Based on the criteria WDFW used to assign categories, placement in the "Approaching Goal" category implies that the expected percent of the recovery goal for the median population in the ESU (of which there is only one) in 5 years is > 100%. However, our analysis, which only used natural origin spawner data (consistent with delisting requirements under the ESA) resulted in a recent-5-year natural-origin spawner abundance geomean of 37% of the recovery goal. We also noted that in no year since ESA listing has the natural-origin spawner abundance exceeded the goal. Assuming the estimated 9% per year growth rate since listing continues in the future, it would take >10 years (rather than <5) to have a geomean natural origin spawner abundance greater than the recovery goal, suggesting that while this ESU is making progress, we cannot yet characterize it as approaching the recovery goal.
Columbia River Chum	Approaching Goal	Not Keeping Pace	WDFW agrees with this final placement. More than 40% of populations are missing data, and it is well known that the populations that are missing data are not doing nearly as well as those with data, but lacking data, it was not possible to formally incorporate this knowledge in our analysis.
Lower Columbia River Steelhead	Approaching Goal	Making Progress	WDFW does not entirely agree with this final placement. Based on the criteria WDFW used to assign categories, placement in the "Making Progress" category implies that the expected percent of the recovery goal for the median population in the ESU (of which there is only one) in 5 years is 50-100%. However, recent 5-year geomean natural-origin spawner abundances for nine of 16 populations are already above recovery goals. Additionally, estimated abundance trends since ESA listing of all populations in the ESU are positive. Finally, the abundance values of the three populations with missing data (North Fork Toutle, Lower Cowlitz, North Fork Lewis) are almost surely also above their recovery goals but these time series have not been confirmed and made available for analysis yet. This suggests that the median population in this DPS currently has a geomean abundance >100% of the recovery goal and is likely to in 5 years, leading to our conclusion that it is approaching recovery and therefore should be in the "Approaching Goal" category.

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